Sheltering In Place And The Likelihood Of Non-Natural Death

Ralph Catalano, M. Maria Glymour, Yea-Hung Chen, and Kirsten Bibbins-Domingo

Correspondence to Ralph Catalano, School of Public Health, University of California, Berkeley, 2121 Berkeley Way, Berkeley, CA 94704 (Email rayc@berkeley.edu)

Author affiliations: School of Public Health, University of California, Berkeley (Ralph Catalano); Institute for Global Health Sciences, University of California, San Francisco (Yea-Hung Chen); Department of Epidemiology and Biostatistics, University of California, San Francisco (M. Maria Glymour, and Bibbins-Domingo).

Funding: None

Conflict of interest: non declared

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ABSTRACT

Increasing hospitalizations for COVID-19 in the United States (US) and elsewhere have ignited debate over whether to reinstate shelter-in-place policies adopted early in the pandemic to slow the spread of infection. The debate includes claims that sheltering in place influences deaths unrelated to infection or other natural causes. Testing this claim should improve the benefit/cost accounting that informs choice on reimposing sheltering in place. We use time-series methods to compare weekly non-natural deaths in California to those in Florida. California was the first state to begin, and among the last to end, sheltering in place while sheltering began later and ended earlier in Florida. During weeks when California had shelter-in-place orders in effect, but Florida did not, the odds that a non-natural death occurred in California rather than Florida were 14.4% below expected levels. Sheltering-in-place policies likely reduce mortality from mechanisms unrelated to infection or other natural causes of death.

Keywords: COVID-19, Shelter in Place, Non-natural deaths

Abbreviations: COVID-19, coronavirus disease of 2019; CDC, Centers for Disease Control and Prevention

As COVID-19 infections and hospitalizations increase in the US and elsewhere, debate over the prudence of shelter-in-place mandates has intensified (1, 2). The debate includes claims that the intervention has induced unintended adverse health effects (3). The "Great Barrington Declaration," for example, justifies opposition to sheltering in place by citing "devastating effects on short and long-term public health (2, 4)." The literature includes claims that the harms of lockdown include increases in deaths not just from impeded access to health care, but also from suicide (5) and intrafamily violence (6). Assessing the accuracy of these claim would seem important if for no other reason than to improve the explicit or implicit accounting of costs presumed to inform the choice whether or not to impose sheltering in place.

Although clinical anecdote (7) supports the intuition of increased non-Covid-19 mortality during sheltering-in-place, the scholarly literature reports mixed findings (8–10). These divergent results likely arise, at least in part, because the observed populations varied in the fraction at risk of what the Centers for Disease Control (CDC) term "natural" death or that "due solely or almost entirely to disease or the aging process" (11). Although information characterizing deaths varies among states, all death certificates in the US use a "manner of death" classification that includes "natural death" (11). Based on data from the last decade, natural deaths account for approximately 89% of deaths in the US (12).

The observed populations also likely varied in the fraction at risk of "non-natural" deaths. How sheltering in place affects these deaths remains, however, even less clear than how it affects natural deaths. As noted above, anecdote implies that suicides (5) and death due to intrafamily violence (7) increased with sheltering in place. Other

reports, however, suggest decreases in such non-natural deaths as those by accidents (13), stranger-on-stranger violence (14), and medical error (15). Taken together, these reports raise an important, question -- what has been the "net effect" of sheltering in place on non-natural deaths? Answering this question requires an estimate of the association between sheltering in place and the incidence of non-natural deaths. The peer-reviewed literature, however, includes no attempts to estimate that association. We attempt such an estimate using data from two US states. We use time-series methods to compare non-natural deaths in California, the first state to begin and among the last to end sheltering in place in early 2020, with those in another large state, Florida, where sheltering in place began late and ended early.

California and Florida responded very differently to the emerging epidemic in early 2020. Large employers, primarily in the technology sector, began telling their California workers to stay at home effective March 8 (16). Counties in the San Francisco Bay Area issued stay-at-home orders effective March 17 (17) and the Governor issued similar orders for the remainder of the state on March 19 (18). California began reopening on May 15 (19). Florida mandated sheltering in place effective April 3 and reopened on May 1 (20, 21). Data that indirectly measure the behavior of households suggest that the citizens of both states reduced mobility and social contacts when shelter-in-place orders were in effect and increased both when orders were removed (22).

METHODS

Data

CDC regularly publishes weekly death counts by state and select causes from 2014 through the most recently accounted week (23). Our tests used deaths in California and Florida for 333 weeks beginning December 29, 2013 (first data available) and ending May 16, 2020 (last week of sheltering in place in California). We subtracted weekly "Natural Cause" deaths from total deaths to estimate the incidence of non-natural deaths in both states. These deaths include, as suggested above, death by accident, suicide, interpersonal violence, drug overdoses, and medical error (i.e., iatrogenesis). State counts of 2020 non-natural deaths by subcategories have not yet been published. In 2019, however, motor vehicle crashes and suicide each accounted for approximately 16% of non-natural deaths in both California and Florida while homicide contributed about 6.5% in each state (12).

We computed the weekly odds that a non-natural death in either state occurred in California. We transformed those odds to natural logarithms (i.e., logits) to allow us to express results as percent difference between observed and expected odds during weeks when California alone sheltered in place. We, therefore, express our "dependent variable" in the equations that follow as $(Y_{ct}/Y_{ft})^e$ in which Y_{ct} and Y_{ft} equal, respectively, the number of non-natural deaths in California and Florida during week t.

Analyses

The weekly odds that a death occurred in California instead of Florida exhibit patterns over time (i.e., autocorrelation) that can lead to an expected or predicted value different from the mean of all weeks. As described below, we identify and model autocorrelation in the logits before shelter in place orders and develop predictions for

ensuing weeks. We then ask whether the observed values differed from predicted during periods when shelter-in-place orders were in place in California but not Florida.

Our test proceeded through 5 steps consistent with time-series conventions used in epidemiology (24,25). First, we used Box-Jenkins methods (26) to identify and model autocorrelation in a 323-week "training period" up to March 8, 2020. The Box-Jenkins approach essentially assumes that values independent of each other and normally distributed passed through an unobserved "filter" that imposed patterns upon them. The method identifies which of a very large family of filters most likely imposed the observed pattern. The methods use well-developed rules to narrow the likely filters to a few models and then applies estimates of "fit" to arrive at the most likely candidate. The model residuals approximate the values that passed through the filter. These "unexpected" values meet the assumptions of traditional tests of association because they are independent of each other (i.e., exhibit no autocorrelation), their expected value equals their mean (i.e., 0), and they exhibit constant variability over time.

The general form of a Box Jenkins model for data like ours is as follows.

$$(Y_{ct}/Y_{ft})^e = c+(1-\theta B^q)/(1-\phi B^p)a_t \qquad [1]$$

$(Y_{ct}/Y_{ft})^e$ is, as described above, the natural log of odds that a non-natural death in California or Florida during week t occurred in California. C is the mean of $(Y_{ct}/Y_{ft})^e$ through week t. θ is a moving average parameter. ϕ is an autoregressive parameter. a is the model error term at week t. B is the "backshift operator" or value of a_t at week t–q or t-p.

Not all time series will exhibit both autoregression and moving averages. Some, those exhibiting both seasonality and the tendency for high or low values to persist into subsequent time periods, can show more than one of either or both. We searched for signals of autocorrelation using methods that detect whether values up to 120 earlier weeks (i.e., “lags) predict observations.

Second, we used the training model to forecast values for the next 10 weeks. Third, we created a 333 week “counterfactual series” by joining the 10 forecasts from step 2 to the 323 fitted values of the training model estimated in step 1. Fourth, we subtracted the 333 counterfactual logits from the observed logits to estimate a residual series. The residual series measures the degree to which the likelihood of a non-natural death in California differed from that expected based on such deaths in Florida and on historical patterns (i.e., autocorrelation). Fifth, we regressed the residual series computed in Step 4 on a binary shelter-in-place variable scored 1 for the weeks when California had shelter-in-place orders in effect, but Florida did not, and scored 0 for all other weeks. The variable equaled 1 for the 3 weeks starting March 8 and ending March 28 and for the 3 weeks starting April 26 and ending May 16.

If sheltering in place changed the likelihood of non-natural deaths, the coefficient for the shelter-in-place variable would appear detectably different from 0. We set detection sensitivity at $P < .05$. Subtracting the antilog of that coefficient from 1 and multiplying the difference by 100 yields the percent difference between observed and expected odds.

RESULTS

Weekly incidence of non-natural deaths ranged from 210 to 511 (mean 399) in California during our test period, and from 176 to 452 (mean 340) in Florida. Figure 1 shows the deaths plotted by week.

The best fitting Box-Jenkins model, identified and estimated in Step 1, for logits in the 323-week training period was as follows:

$$(Y_{ct}/Y_{ft})^e = 0.163+1/[(1-0.314B)(1-0.176B^5)(1-0.254B^7)]a_t \qquad [2]$$

The constant, 0.163 (SE 0.013) and 3 autoregressive parameters (i.e., 0.314, 0.176, and 0.254) all exceeded at least twice their standard errors (i.e., 0.054, 0.057, and 0.056 respectively). The 3 autoregressive parameters imply that including the values of $(Y_{ct}/Y_{ft})^e$ at weeks t-1, t-5 and t-7 improves, over using only the mean of past values, the model's prediction at week t.

The results of Steps 2 and 3, in which we construct a counterfactual series by joining values forecasted for weeks 324 through 333 to the fitted values during to the training weeks, appear in Figure 2 as a line. We show only the last year of data to allow better resolution of the information. The points in Figure 2 show the observed values for the 52 weeks. The residual series, computed in Step 4 by subtracting the full 333 expected from observed values, became the dependent variable for our test.

Step 5, in which we regress the residual series on our shelter-in-place binary variable yielded a regression coefficient of -0.155 (SE 0.038). This estimate implies that the odds of a nonnatural death in the two states occurring in California detectably *decreased* by 14.4% when California alone sheltered in place.

To express our results in an alternative, perhaps more meaningful metric, we estimated how many Californians would have had to die non-natural deaths during the 6 weeks when California, but not Florida, sheltered in place to equal the expected (i.e., counterfactual) odds. This calculation implied that sheltering in place saved 407 lives or 68 per week.

We anticipated that the association between sheltering in place and non-natural deaths may have changed if, as time passed, Californians became less risk averse and complied less with rules. To test this possibility, we created early and late sheltering in place binary variables. We scored the early sheltering variable 1 for the 3 weeks in which California alone began sheltered in place (i.e., from March 8 through March 28) and 0 otherwise. The late sheltering variable equaled 1 for the 3 weeks starting April 26 and ending May 16. We then early repeated our main test but substituted these two variables for the single shelter-in-place variable. The estimated coefficient for early sheltering was -0.186 (SE = 0.053) implying a 17% decrease in the odds that a death in the two states occurred in California. The coefficient for the late sheltering was -0.123 (SE = 0.053) suggesting a drop of 11.6%

We tested whether our main finding would appear if we allowed the Box-Jenkins modeling in Step 1 to include all 333 months. The counterfactual for any week during the pandemic, therefore, results not from applying pre-pandemic autocorrelation to

forecasts of earlier weeks as in our main test, but from applying autocorrelation in the entire series to observed intra-pandemic values. The approach, though more conservative, has the benefit of anticipating the response of the population to higher-than-expected death counts during the pandemic. Applying this approach, we found autocorrelation essentially the same as in the pre-pandemic data. We also detected, as in our main test, a downward shift the log odds during weeks when California, but not Florida, sheltered in place. The estimated coefficients in the model were as follows.

$$(Y_{ct}/Y_{ft})^{e} = 0.163 - 0.132S+1/[(1-0.321B)(1-0.177B^{5})(1-0.257B^{7})]a_t \quad [3]$$

S is the binary shelter in place variable used in our main test. All other notation is the same as in equation 1 above. All the coefficients were at least twice their standard errors. Taking the antilog of -0.132 and subtracting the result from 1 found that the log odds dropped by 12.4% when California, but not Florida, sheltered in place.

We also performed a falsification test by repeating our analyses but replacing the binary shelter-in place variable with another that scored the same weeks of the year as "1" but for 2019 rather than 2020. The coefficient for this "correct week, wrong year" variable did not detectably differ from 0 (i.e., -0.052; SE = 0.038).

As noted at the outset, we marked the start of sheltering in place in California as the week ending March 14 because, unlike Florida, many of the State's largest employers told their workers to stay home (16). We estimated how different our results would appear if we restricted sheltering in place only to those weeks in which

government required the closing of non-essential businesses. This would move the start of the first shelter-in-place period to the week ending March 21 and reduce the period to 2 weeks rather than 3. Excluding the first week from California's shelter in place period, we estimated the shelter-in-place policy reduced the odds of non-natural death in California by 12.7%.

DISCUSSION

Time-series modeling using seven years of weekly non-natural deaths shows that when California ordered sheltering in place but Florida did not, Californians yielded unexpectedly few non-natural deaths. We estimate an approximate 14% reduction below values expected from non-natural deaths in Florida and from historical patterns. The estimated benefit appears larger at the outset of mandated sheltering in place than near its suspension.

Our findings have implications for epidemiologic as well as policy research. They imply that to accurately estimate how averted medical care might have raised mortality in the pandemic, epidemiologists must account for the fact that stay at-home orders reduced mortality, which may mask the former association. This circumstance similarly implies that policy analysts attempting to estimate the benefits and costs of sheltering in place need to use prior epidemiologic research with care. The scholarly work intended to estimate deaths accruing to impeded access to routine medical care has included non-natural deaths in the accounting. Using results from research that does not exclude those deaths could lead to an underestimate of deaths and their costs.

Advantages of our approach include that Box-Jenkins modeling accounts for autocorrelation including trends, cycles (e.g., seasonality), and the tendency for a series to remain elevated or depressed after high of low values. Using Florida as a comparison population, moreover, allows us to control for events, unrelated to shelter-in-place orders, that influenced non-natural deaths in both California and Florida.

Limitations of our approach include that currently available data do not allow us to distinguish among types of non-natural deaths. Nor can we identify non-natural deaths to which COVID-19 directly contributed (e.g. accidents resulting from hypoxia secondary to coronavirus infection), as has been suggested in the literature (27). Further research should, when CDC publishes more detailed data, test the intuitive hypothesis that some types of these deaths, those by auto crash and medical error, for example, decrease during shelter in place while others, those by suicide and intrafamily violence for instance, may increase.

We acknowledge that differences between California and Florida other than sheltering-in-place policies could have influenced our finding. We note, however, that other differences could have induced our results only if they met 2 criteria. First, they appeared (or disappeared), by chance, *only* in the 2, 3-week periods when California, but not Florida, sheltered in place. Second, they caused either fewer non-natural deaths in California or more non-natural deaths in Florida. We know of no differences other than sheltering in place policies that meet these criteria.

We do not claim a full accounting of the costs associated with non-natural deaths in California or Florida. We did not include, for example, the morbidity of non-fatal injuries averted by sheltering in place. CDC data indicate that for every 1 motor vehicle

crash fatality, for example, there are 9 non-fatal hospitalizations and 88 individuals treated and released from emergency departments (28). These facts suggest that the reductions in non-natural fatalities that we measured trace much larger reduction in morbidity and disability. We further note that to the extent Floridians sheltered in place without state requirements to do so, our approach underestimates the impact of the shelter-in-place policy in California.

We did not attempt to estimate the association between non-natural deaths and social distancing induced by circumstances other than shelter-in-place orders. Mobility measured by household surveys or cellphone movement (22), for example, declined whether or not shelter-in-place orders were in effect and, in turn, affected non-natural deaths. Future work should include such indicators of mobility to estimate the separate associations of non-natural death with differing interventions.

The association we find will likely vary by time and place depending on the mechanisms that connect sheltering in place with non-natural fatalities. The association of sheltering in place with, for example, physical mobility has reportedly fluctuated over time and varies with the sociodemographic and environmental characteristics of communities (29).

Our findings imply that shelter-in-place orders widely adopted in response to the COVID-19 pandemic likely reduced not only contagious illness but also non-natural mortality. Ignoring averted non-natural deaths when assessing the utility of shelter-in-place policies will, therefore, lead to an underestimate of benefits.

REFERENCES

1. Coronavirus: WHO head calls herd immunity approach 'immoral'. BBC News. https://www.bbc.com/news/world-54518286?at_medium=custom7. Published October 12, 2020. Accessed November 29, 2020.

2. Mandavilli A, Stolberg S. A Viral Theory Cited by Health Officials Draws Fire From Scientists. New York Times. October 19, 2020): https://www.nytimes.com/2020/10/19/health/coronavirus-great-barrington.html?action=click&module=Top%20Stories&pgtype=Homepage.

3. Qiu L. Trump's Baseless Claim That a Recession Would Be Deadlier Than the Coronavirus. New York Times. March 26, 2020: https://www.nytimes.com/2020/03/26/us/politics/fact-check-trump-coronavirus-recession.html/.

4. Lenzer J. Covid-19: Group of UK and US experts argues for "focused protection" instead of lockdowns. *BMJ*. 2020;371:m3908. Published 2020 Oct 7. doi:10.1136/bmj.m3908

5. Reger MA, Stanley IH, Joiner TE. Suicide Mortality and Coronavirus Disease 2019-A Perfect Storm? *JAMA Psychiatry*. 2020;77(11):1093-1094.

6. Campbell A. An increasing risk of family violence during the Covid-19 pandemic: Strengthening community collaborations to save lives. *Forensic Science International: Reports*. **2**, 100089. doi:10.1016/j.fsir2020.100089 (2020)

7. Rosenbaum L. The Untold Toll - The Pandemic's s on Patients without Covid-19. *N Engl J Med*. 2020;382(24):2368-2371.

8. Woolf SH, Chapman DA, Sabo RT, Weinberger DM, Hill L. Excess Deaths From COVID-19 and Other Causes, March-April 2020. *JAMA*. 2020;324(5):510-513.

9. Mills EHA, Møller AL, Gnesin F, et al. National all-cause mortality during the COVID-19 pandemic: a Danish registry-based study. *Eur J Epidemiol*. 2020;35(11):1007-1019.

10. Catalano R, Casey JA, Bruckner TA, Gemmill A. Non-COVID-19 deaths after social distancing in Norway [published online ahead of print, 2020 Nov 9]. *Eur J Epidemiol*. 2020; 35(11):1021-1024..

11. National Center for Health Statistics (US). Medical examiners' and coroners' handbook on death registration and fetal death reporting. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics; 2003. https://www.cdc.gov/nchs/data/misc/hb_me.pdf. Accessed November 29, 2020.

12. Underlying Cause of Death, 1999-2018 Request. Centers for Disease Control and Prevention. https://wonder.cdc.gov/ucd-icd10.html. Accessed November 29, 2020.

13. Shilling F, Waetjen D. Special Report (Update): Impact of COVID19 Mitigation on Numbers and Costs of California Traffic Crashes. (Road Ecology Center, UC Davis, 2020,

https://roadecology.ucdavis.edu/files/content/projects/COVID_CHIPs_Impacts.pdf), Accessed November 29, 2020.

14. Chapman B. New York City Crime Falls as Coronavirus Takes Hold. New York Times. March 23, 2020: https://www.wsj.com/articles/new-york-city-crime-falls-as-coronavirus-takes-hold-11584998470. Accessed November 29, 2020.

15. Thorley P. The early pandemic paradox: Fewer deaths in the first 4 months of 2020 compared to previous years. Medical Express June 22, 2020: https://medicalxpress.com/news/2020-06-early-pandemic-paradox-deaths-months.html. Accessed November 29, 2020.

16. Levy,A. The tech industry's early work-from-home mandates helped California and Washington flatten the curve. CNBC. April 16, 2020: https://www.cnbc.com/2020/04/16/california-and-washington-tech-work-from-home-edicts-flattened-curve.html. Accessed November 29, 2020.

17. Berman R. The City That Has Flattened the Coronavirus Curve. The Atlantic. April 12, 2020: https://www.theatlantic.com/politics/archive/2020/04/coronavirus-san-francisco-london-breed/609808/. Accessed November 29, 2020.

18. Executive Department State of California. Executive Order N-33-20. https://www.gov.ca.gov/wp-content/uploads/2020/03/3.19.20-attested-EO-N-33-20-COVID-19-HEALTH-ORDER.pdf. Accessed November 29, 2020.

19. Executive Department State of California. Executive Order N-60-20. https://www.gov.ca.gov/wp-content/uploads/2020/05/5.4.20-EO-N-60-20.pdf. Accessed November 29, 2020.

20. State of Florida Office of the Governor. Executive Order Number 20-91. https://www.flgov.com/wp-content/uploads/orders/2020/EO_20-91-compressed.pdf. Accessed November 29, 2020.

21. New York Times. See How All 50 States Are Reopening (and Closing Again). October 20, 2020: https://www.nytimes.com/interactive/2020/us/states-reopen-map-coronavirus.html. Accessed November 29, 2020.

22. Covid-19 Social Distancing Scoreboard. Unacast. https://www.unacast.com/covid19/social-distancing-scoreboard?view=state. Accessed November 29, 2020.

23. United States Centers for Disease Control and Prevention. Weekly Counts of Deaths by State and Selected Causes, 2019-2020 (CDC, 2020, https://data.cdc.gov/NCHS/Weekly-Counts-of-Deaths-by-State-and-Select-Causes/muzy-jte6). Accessed November 29, 2020.

24. Bernal JL, Cummins S, Gasparrini A. Interrupted time series regression for the evaluation of public health interventions: a tutorial. *Int J Epidemiol*. 2017;46(1):348-355.

25. Catalano R, Serxner S. Time series designs of potential interest to epidemiologists. *Am J Epidemiol*. 1987;126(4):724-731.

26. Box G, Jenkins G, Reinsel G. *Time series analysis: forecasting and control.* John Wiley & Son; 2015.

27. Wrigley-Field E, Garcia S, Leider J, et al. Racial Disparities in COVID-19 and Excess Mortality in Minnesota. Minnesota Population Center. https://assets.ipums.org/_files/mpc/wp2020-08.pdf. Published November 2020. Accessed January 19, 2021.

28. United States Centers for Disease Control and Prevention. CDC report shows motor vehicle crash injuries are frequent and costly. Centers for Disease Control and Prevention. https://www.cdc.gov/media/releases/2014/p1007-crash-injuries.html. Published October 7, 2014. Accessed November 29, 2020.

29. Hamidi S, Zandiatashbar A. Compact development and adherence to stay-at-home order during the COVID-19 pandemic: A longitudinal investigation in the United States. *Landscape and urban planning*. 2020;205:103952

Figure 1. Weekly counts of non-natural deaths in California (circles) and Florida (line) for 333 weeks starting December 29, 2013 and ending May 16, 2020. Week ending March 14, 2020 marked with triangle.

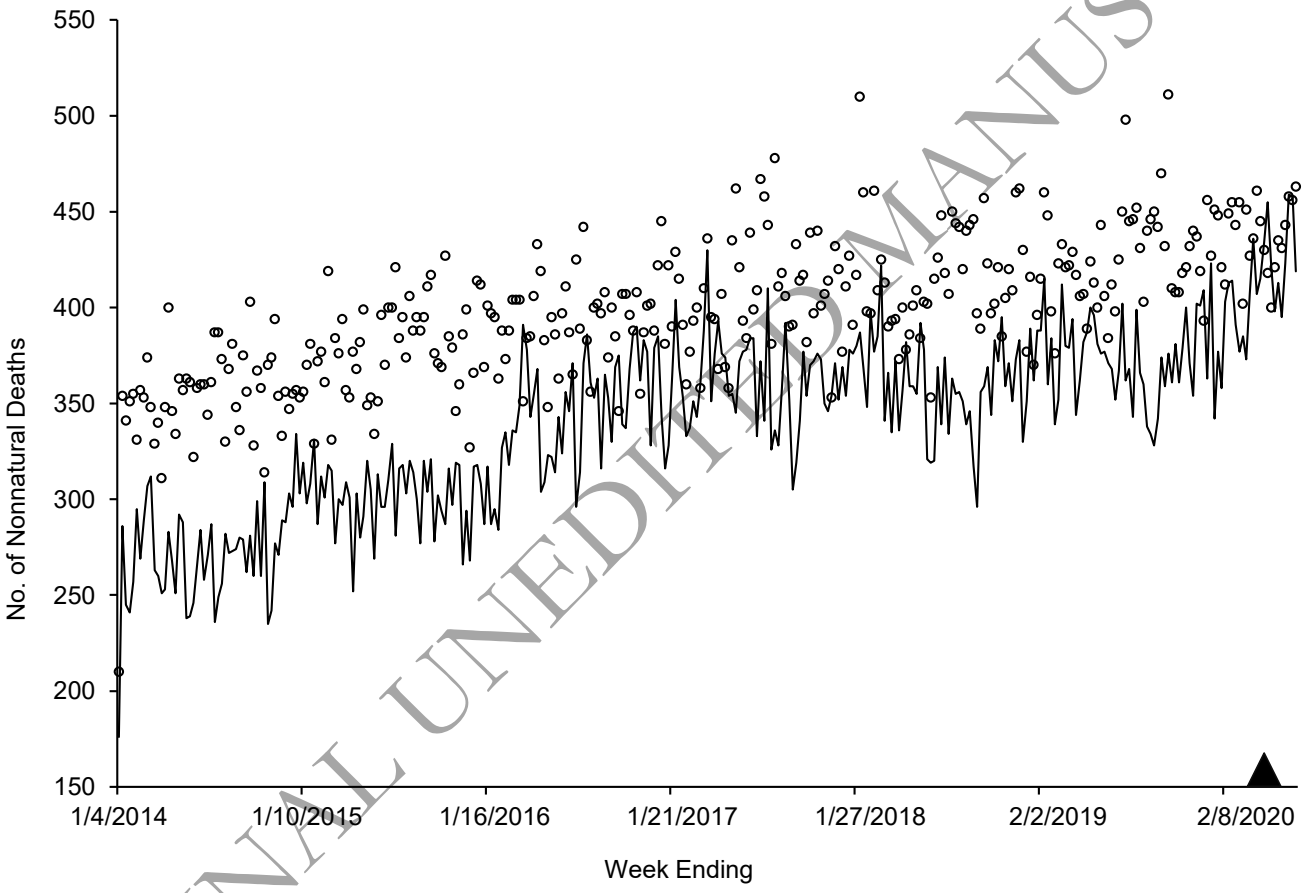

Figure 2. Expected (line) and observed (points) weekly log odds that a non-natural death in California and Florida occurred in California. Boxes show weeks during which California but not Florida sheltered in place (n = 52 weeks beginning May 19, 2019 and ending May 16, 2020).